"High Temperature Behavior Of Copper"

Thesis Submitted
By
Ramkumar Kesharwani
Roll No: 208ME208

In the partial fulfillment for the award of Degree of
Master of Technology
In
Mechanical Engineering

Department of Mechanical Engineering
National Institute of Technology
Rourkela-769008, Orissa, India.
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Rourkela

CERTIFICATE

This is to certify that thesis entitled, "High Temperature behavior of Copper" submitted by Mr. "Ramkumar Kesharwani" in partial fulfillment of the requirements for the award of Master of Technology Degree in Mechanical Engineering with specialization in "Production Engineering" at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

Date:

Prof. S.K. Sahoo

Dept. of Mechanical Engineering

National Institute of Technology

Rourkela-769008

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Place: Ramkumar Kesharwani

Date: Roll No. : 208ME208

Abstract

The high temperature properties of pure & alloy copper have been investigated in the temperature range of room temperature to 500°C. Substantial decrease in yield strength and ultimate strength for both pure & alloy copper were observed with increasing temperature. The Ductility or percentage elongation was also found decreasing with increase in temperature for both pure & alloy copper.

If comparison is made between pure copper & alloy copper then, the yield strength and ultimate strength of alloy copper were found slightly greater than that of the pure copper, even at elevated temperature also. But the ductility or % elongation for pure copper was found slightly greater than that of the alloy copper even at elevated temperature. Ductile mode of fracture was observed even at elevated temperature.

Substantial decrease in Strain Hardening Exponent \`n\` with increase in Temperature both for pure & alloy copper were observed; but the strengthening coefficient \`A\` decreases with increase in temperature for Pure Copper, and initially increases up to 373K and after that decreases for Alloy Copper, due to phase change of carbon atoms (present in Alloy Copper) at higher Temperature. A generalized characteristic equation for both tested materials has been proposed, which can take effect of temperature.

Key words: Yield Strength, Ultimate Strength, Ductility, % Elongation, True Stress, True Strain.

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Nomenclature

RT	Room Temperature
SEM	Scanning Electron Microscopy
U.S.	Ultimate Stress
UTM	Universal Testing Machine
Y.S.	Yield stress

Symbols

A	Strengthening Coefficient
D	Diameter
E	Young modulus of Elasticity
n	Strain hardening exponent
K	Temperature
σ	True Stress
ε	True Strain

Chapter 1

Introduction

1. Introduction:

1.1 Introduction to tensile test.
1.2 Introduction to Copper.

1.1 Introduction to Tensile Test

The mechanical properties of materials used in engineering are determined by tests performed on small specimens of the material. The tests are conducted in materials testing laboratories equipped with testing machines capable of loading the specimen in a variety of ways, including static and dynamic loading in tension and compression. One such machine is shown in fig1.1. A test specimen is in the place in the middle of the loading assembly, and the control console is the separate unit on the left.

Fig. 1.1 General purpose testing machine.

In order that test results may be compared easily, the dimensions of test specimens and the methods of applying loads have been standardized. One of the major standards organizations is the *American society for Testing and Materials* (ASTM), a national technical society that publishes specifications and standards for materials and testing. Other standardizating organizations are the *American Standards Association* (ASA) and the *National Bureau of Standards* (NBS).

The most common materials test is the **tension test**, in which tensile loads are applied to a cylindrical specimen like the one shown in fig. 1.2. The ends of the specimen are enlarged where they fit in the grips so that failure will occur in the central uniform region, where the stress is easy to calculate, rather than near the ends, where the stress distribution is complicated under load. The device at the middle which is attached by two arms to the specimen, is an **extensomete**r that measures the elongation during loading.

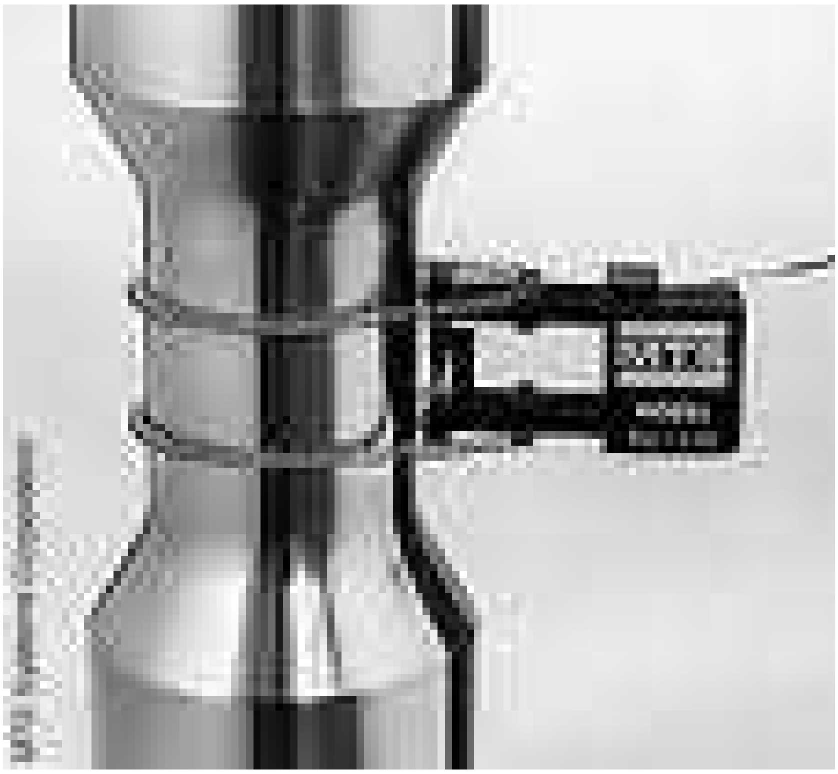


Fig. 1.2 . Specimen with Extensometer.

The ASTM standard tension specimen has a diameter of 0.5 in. and a gage length of 0.2 in. between the gage marks, which are the points where the extensometer arms are attached to the specimen, as shown in fig. 1.2. As the specimen is pulled, the load *P* is measured and recorded, either automatically or by reading from a dial. The elongation over the gage length is measured simultaneously with the load, usually by mechanical gages of the kind shown in fig. 1.2, although electric-resistance strain gages are also used. In a **static test**, the load is applied very slowly; however, in a **dynamic test**, the rate of loading may be very high and also must be measured because it affects the properties of the materials.

The axial stress σ in the test specimen is calculated by dividing the load *P* by the cross-sectional area *A*. When the initial area of the bar is used in this calculation, the resulting stress is called the **nominal stress** (other names are conventional stress and engineering stress). A more exact value of the axial stress, known as the **true stress**, can be calculated by using the actual area of the bar, which can become significantly less than the initial area for some materials.

The average axial strain in the bar is found from the measured elongation δ between the gage marks by dividing δ by the gage length *L*. If the initial gage length is used (for instance, 2.0 in.), then the nominal strain is obtained. Of course, the distance between the gage marks increases as the tensile load is applied. If the actual distance is used in calculating the strain, we obtain the true strain, or natural strain.

After performing a tension test and determining the stress and strain at various magnitude of the load, we can plot a diagram of stress versus strain. Such a **stress-strain diagram** is characteristic of the material and conveys important information about the mechanical properties and type of behavior. The first material we will discuss is **structural steel**, also known as mild steel o low carbon steel. Structural steel is one of the most widely used materials, being the principal steel used in buildings, bridges, towers, and many other types of construction. A stress-strain diagram for a typical structural steel in tension is shown in fig 1.3 (not to scale). Strains are plotted on the horizontal axis and stress on the vertical axis. The diagram begins with a straight line from *O* to *A*. in this region, the stress and strain are directly proportional, and the behavior of the material is said to be **linear**. Beyond point *A*, the linear relationship between stress and strain no longer exists; hence, the stress at *A* is called the **proportional limit**. For low-carbon steel, this limit is in the range 30 to 40 ksi, but high-strength steels (with higher carbon content plus other alloys) can have proportional limits of 80 ksi and more.

With an increase in the load beyond the proportional limit, the strain begins to increase more rapidly for each increment in stress. The stress-strain curve then has a smaller and smaller slope, until, at point *B*, the curve becomes horizontal. Beginning at this point, considerable elongation occurs, with no noticeable increase in the tensile force (from *B* to *C* on the diagram). This phenomenon is known as **yielding** of the material, and the stress at point B is called the **yield stress**, or **yield point**. In the region from *B* to *C*, the material becomes perfectly plastic, which means that it can deform without an increase in the perfectly plastic region is typically 10 to 15 times the elongation that occurs between the onset of loading and the proportional limit.

After undergoing the large strains that occur during yielding in the region *BC*, the steel begins to **strain harden**. During strain hardening, the material undergoes charges in its atomic and crystalline structure, resulting in increased of material to further deformation. Thus, additional elongation requires an increase in the tensile load, and the stress-strain diagram has a positive slope from *C* to *D*. The load eventually reaches its maximum value, and the corresponding stress (at point *D*) is called the **ultimate stress**. Further stretching of the bar is actually accompanied by a reduction in the load, and **fracture** finally occurs at a point such as *E* on the diagram.

Lateral contraction of the specimen occurs when it is stretched, resulting in a decrease in the cross-sectional area, as previously mentioned. The reduction in area is too small to have a noticeable effect on the reduction begins to alter the shape of the diagram. Of course, the true stress is larger than the nominal stress because it is calculated with a smaller area. In the vicinity of the ultimate stress, the reduction in area of the bar becomes clearly visible and a pronounced **necking** of the bar occurs.(Fig. 1.4). If the actual cross sectional area at the narrow part of the neck is used to calculate the stress, the **true stress-strain curve** will follow the dashed line *CE*` in fig 1.2. The total load the bar can carry does not indeed diminish after the ultimate stress is reached (curve *DE*), but this reduction is due to the decrease in area of the bar not to a loss in strength of the material itself. In reality, the material withstands an increase in stress up to failure (point *E*`). For most practical purposes, however, the conventional stress-strain curve *OABCDE*, which is based upon the original cross-sectional area of the specimen and hence is easy to calculate, provides satisfactory information for use in design.

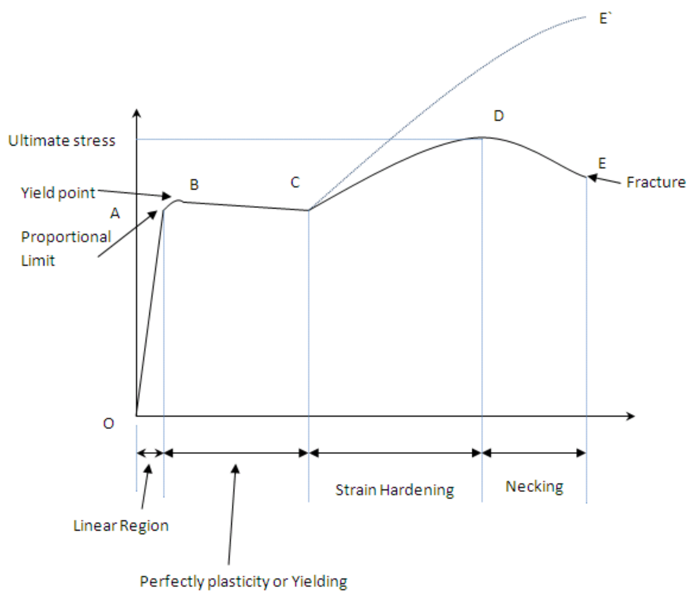


Fig.1.3 Stress-strain curve for structural steel (not to scale).

The diagram in fig 1.3 shows the general characteristics of the stress-strain curve for mild steel, but its proportions are not realistic because, as already mentioned, the stain that occurs from *B* to *C* may be 15 times the strain occurring from *O* to *A*. Furthermore, the strains from *C* to *E* are many times greater than those from *B* to *C*.

Many **aluminum alloy** posses considerable ductility, although they do not have a clearly definable yield point. Instead, they exhibit a gradual transition from the linear to the nonlinear region, as shown by the above stress-strain diagram. Aluminum alloy suitable for structural purposes are available with proportional limits in the range 10 to60 ksi and ultimate stresses in the range 20 to 80 ksi.

When a material such as aluminum does not have an obvious yield point and yet undergoes large strains after the proportional limit is exceeded, an arbitrary yield stress may be determined by the **offset method**. A line is drawn on the stress-strain diagram parallel to the initial linear part of the curve but is offset by some standard amount of strain, such as .002 (or 0.2%). The intersection of the offset line and the stress-strain curve defines the yield stress. Since this stress is determined by an arbitrary rule and is not an inherent physical property of the material, it should be referred to as the **offset yield stress**. For a material such as aluminum, the offset yield stress is slightly above the proportional limit. In the case of structural steel, with its abrupt transition from the linear region to the region of plastic stretching, the offset stress is essentially the same as both the yield stress and the proportional limit.

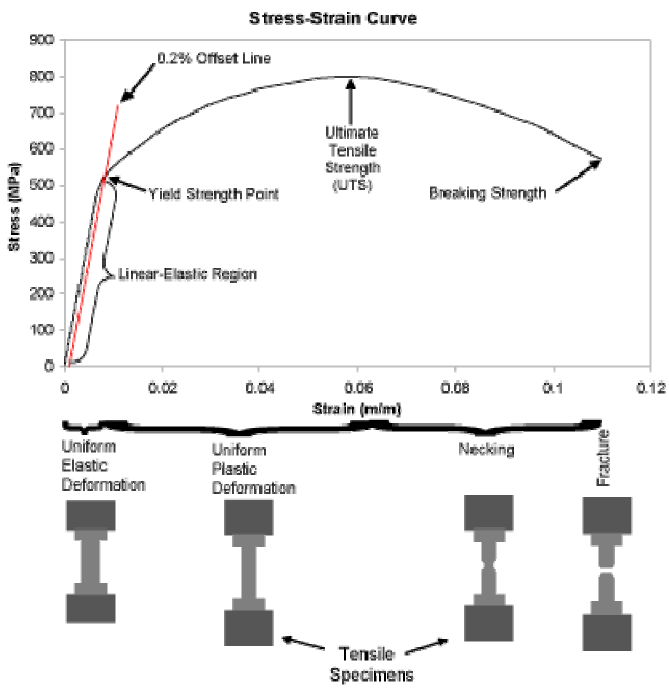


Fig1.4 (0.2%) offset stress-strain curve

1.2 Introduction to copper:

Copper, the reddish metal, apart from gold the only metallic element with a color different from a gray tone, has been known since the early days of the human race. It has always been one of the significant materials, and today it is the most frequently used heavy nonferrous metal. The main grades of raw copper used for cast copper base alloy are:

(a) High conductive copper (electrolytic) having not less than 99.9% Cu. The oxygen content may be of the order 0.40%, Pb and Fe less than 0.005% each Ag 0.002% and Bi less than 0.001% electrolytic copper is used for electrical purposes.

(b) Deoxidized copper having not less than 99.85% Cu, less than 0.05% As, 0.035 Fe, and 0.003% Bi, other elements may be of the order of 0.005% P, 0.01% Pb, 0.10% Ni, 0.003% and 0.005% Ag and Sb respectively.

(c) Arsenical deoxidized copper having 0.45 As, 0.04% P, and remaining copper. It is used for welded vessels and tanks.

(d) Arsenical touch pitch copper containing 0.4% As, 0.065% oxygen, 0.02% Pb,0.15 %Ni, 0.006% Ag, 0.01% Sb and less than 0.005% Bi, less than 0.020% Fe and remaining copper.

(e) Oxygen free copper contains 0.005% Pb,0.001% Ni,0.001% Ag, and less than 0.0005% and 0.001% Fe and Bi respectively. It is melted and cast in Ion oxidizing atmosphere.

Various properties of copper:

1. Atomic and Nuclear properties:

The atomic number of copper is 29, and the atomic mass A is 63.546 ±0.003. Copper consists of two natural isotopes, 63_{Cu} (68.94%) and 63_{Cu}(31.06%). There are also nine synthetic radioactive isotopes with atomic masses between 59 and 68, of which 67Cu has the longest half-life, Ca.58.5 h.

Crystal Structure : At moderate pressure, copper crystallizes from low temperatures up to its melting point in a cubic-closest-packed (ccp) lattice, type A1 (also F^1 or Cu) with the coordination number 12 x-ray structure analysis yield the following dimensions (at 20°C):

Lattice constant	**0.36152 nm**
Minimum Inter atomic distance	**0.2551 nm**
Atomic Radius	**0.1276 nm**
Atomic Volume	**7.114 cm^3/mol.**
Density	**8.89 g/cm^3**

2. **Mechanical Properties:** Important mechanical values are given in Table 1.1

Table 1.1: Mechanical Properties of copper at room temperature

Property	Unit	Annealed(soft) Copper	Cold-worked(hard)Copper
El;astic modules	GPa	100-120	120-130
Shearing modulus	GPa	40-45	45-50
Poisson`s ratio		0.35	
Tensile strength	MPa	200-250	300-360
Yield strength	MPa	40-120	250-320
Elongation	%	30-40	3-5
Brinell hardness	(HB)	40-50	80-110
Vickers hardness	(HV)	45-55	90-120
Scratch hardness		3	

3. **Thermal Properties**: Important thermal values are compiled in Table 1.2

Table 1.2: Thermal properties of Copper

Property	Unit	Value
Melting point	k	1356
Boiling point	k	2868
Heat of fusion	j/g	210
Heat of Vaporization	j/g	810
Vapor pressure(at mp)	j/g	.073
Specific heat capacity at 293k (20·C) 1 bar	Pa	.385 .494
Average specific heat273-573k (0-300·C) 1bar	$Jg^{-1}\ k^{-1}$	.411
Cofficient of linear thermal expansion	k^{-1}	19.8
Thermal conductivity(at 293 k)	$Wm\text{-}1k^{-1}$	394

4. Chemical Properties:

In the periodic table, copper is placed in period 4 and subgroup IB; therefore, it behaves as a typical transition metal. It appears in oxidation states +1 to +4, its compounds are colored, and it tends to form complex ions.

At relatively low temperature copper is the most stable state, but above 800°C, copper predominates.

Electron distribution: $1S^2$, $2S^2$, $2P^6$, S^2, $3P^{6,}$ $3D^{10}$, $4S^1$

Occurrence: In the upper part of the earth`s crust (16 km deep), the average copper content is ca.50 ppm. Older estimates were nearly 100 ppm, while recent spectral analysis values are 30-40 ppm. Copper is 26th in order of abundance of the elements in the accessible sphere of the earth.

Copper alloys:

- Copper alloys normally possess excellent corrosion resistance, electrical and thermal conductivities and formability.
- Some copper alloys combine high strength and corrosion resistance, a combination desirable for marine applications.
- Some copper alloys because of their wearing properties high hardness or corrosion resistance are used as surfacing metals.
- Some copper alloys are selected for decorative applications because of appearance.
- Elements such as aluminum, zinc, tin, beryllium, nickel, silicon, lead etc, form alloys with copper.

Copper alloys may be classified as:

(a) High copper alloys:

High copper alloys contain 96.0 to 99.3% copper.

They possess enhanced mechanical properties due to the addition of small amount of alloying elements such as chromium, zirconium, beryllium and cadmium. A few typical high copper alloys are:

(1) Cu, 1% Cd
(2) Cu, 0.8 % Cr
(3) Cu, 0.12-0.30%Zr,
(4) Cu, 1.5-2.0% Be.

Such alloys are used for electrical and electronic components, as resistance welding electrodes, wire conductors, diaphragms and pump parts.

Some general properties of copper:

(a) Excellent resistance to corrosion.
(b) Non magnetic properties.
(c) Easy to work, it is ductile and malleable.
(d) Moderate to high hardness and strength.
(e) High thermal and electrical conductivity.
(f) It can be easily polished, plated and possesses a pleasing appearance.
(g) Resistance to fatigue, abrasion and corrosion.
(h) It can be soldered, brazed or welded.
(i) Very good machinability.
(j) Each of forming alloys with other elements like Zn, Sn, Al, Pb, Si. Ni, etc.

Copper is used for following:

(a) Electrical parts,
(b) Heat exchanger,
(c) Screw machine products,
(d) For making various copper alloy, such as Brass and **B**ronze.
(e) Household utensils, etc.
(f) Electrodes of EDM, ECM, resistance welding, etc.

Chapter-2

Background Literatures

2.1 Literature Review:

Since now a day copper is highly used for different mechanical purposes like; used as a electrode material in EDM, ECM, and in resistance welding, heat exchanger at higher temperature. So the high temperature behavior of copper is essential to know. So to know about it various literatures have been reviewed. Out of them some important literatures are discussed here:

- Nagarjuna s., srinivas m., [1], Introduces the high temperature tensile properties of a Cu-1.5 wt% Ti alloy in the temperature range of 100-500·C and it is found by him, that the high temperature tensile properties of Cu-1.5 Ti alloy are comparable at 300.C and even better at 425.C than those of Cu-1.5 Ti-2.5 Sn, Cu-1.5 Ti-2.5 Sn-0.5 Cr and Cu_0.65 Be_2.7 Co alloy.
- Luo Anhua, Shin S. Kwang, Jacobson L. Dean, [2], Introduces the tensile properties of W-Re-1Wt.% ThO_2 alloy with rehenium concentration of 0-26 wt% in a temperature range of 1600-2600K.
- Radovic M., Barsoum M.W., El-Raghy T., Seidensticker J., Widerhorn S., [3], Introduces the functional dependence of the tensile response of fine-grained (3-5μm) Ti_3SiC_2 samples on strain rates in the 25-1300.C temperature range.
- Nagarjuna S., Srinivas M.,[4] Introduces tensile properties of a Cu–1.5 wt.% Ti alloy in the temperature range of100–550 °C. Substantial increase in yield and tensile strengths of solution treated alloy is observed with increasing temperature, with a peak at 450 °C and decrease in strength beyond this temperature.
- Nagarjuna S., Srinivas M.,[5] Introduces the high temperature tensile properties of solution treated, cold worked and peak aged Cu–1.5 wt.%Ti and Cu–4.5 wt.%Ti alloys in the temperature range fromroom temperature (RT) to 550 ◦C. Yield strength (YS) and tensile strength (TS) of Cu–1.5Ti alloywere found to be independent of test temperature up to 350 ◦C and decreased thereafter, up to 550 ◦C.
- Quinlan M.F. , Hillery M.T.,[6] Introduces the flow stress of any given material in metal forming is sensitive to the working temperature and the rate of deformation. Research at high strain rates on tensile specimens at elevated temperatures was carried out in the 1940s by Manjoine and Nadai. Little work has been done on this topic since.

- V. Caballero, S. K. Varma, [7], Introduces the effect of stacking fault energy (SFE) on the evolution of microstructures during room temperature tensile testing at two strain rates of 8:3£10¡4 and 1:7£10¡1/s in pure copper, Cu-2.2%Al, and Cu-4.5%Al alloys with SFE values of, approximately, 78, 20 and 4 mJ/m2, respectively.
- Arthur k. lee, Nicholas J. Grant, [8], Introduces the property of two high temperature, high strength, high conductivity ingot-base copper alloys. Tensile test at 293K and stress rupture tests at 693K were performed.
- Gholam H., Amin H., Ali S., [9], Introduces the deformation mechanism of ductile fracture of two materials, copper and st37 steel, including void nucleation, void growth and void coalescence at different strain rates.

2.2 Objective of the project:

The objective of the project work is to know the high temperature tensile behavior of copper & its alloy in between (RT-500.C) temperature range and then find out the following:

1. The ductility or % elongation at higher temperature.
2. Effect on yield strength & ultimate tensile strength at higher temperature.
3. Find out the values of True stress & True strain, and then find out the value of strengthening coefficient & work hardening exponent.
4. Plot the graphs and fit the curves.
5. With the help of curves fitted derive the equations of curves.
6. Make the analysis and find out the results.

2.3 Organization of thesis:

The thesis is organized into five chapters. The chapter-1 contains the introduction. Here the basic introduction to stress-strain diagram and tensile test and then introduction to copper & its alloy have been discussed. The chapter-2 contains the literature review. The chapter-3 contains the experimentations. Here information about the experiment has been discussed. The chapter-4 contains results & discussion. Whatever observations have been taken during the experiments, the results of those are presented here in the form of graphs. Finally chapter-5 presents the overall conclusion of the research output of this project.

Chapter-3

Experimentation

Experimentation:

Before discussing about the experiments let us know about the testing machine. For testing the specimen the "INSTRON" (SATEC series) machine was used .here some basic features of the machine are there.

3.1 The INSTRON (Static series, 600kn):

This machine is designed for the high capacity tension, compression; bending and shear test .The main design of the INSTRON Model provides the ultimate versatility. This machine has used here for tensile test of copper specimen at higher temperature.

Features:

- Single ultra-large test space accommodates an assortment of specimen size grip fixture furnace and extensometer.
- Optional Hydraulic Lifts and Locks allow quick and easy repositioning of the crosshead over the length of the column.
- It provides the fast test speed and long test stroke capability to meet variety of testing requirements.
- Alignment head maintains accurate alignment of the load string over the entire stroke of the actuator.
- Choice of Partner or Bluehill Universal Materials Software provides the ultimate in ease-of-operation and flexibility.
- Optional full capacity hydraulic wedge grips offer fully open-front design making specimen loading efficient and safe for the operator.

Model range:

600KN Capacity

Figure 3.1 INSTRON static

Tensile test also known as tension test has probably the most fundamental type of mechanical test you may be perform on material. Tensile test is simple, relatively inexpensive, and fully standardized. By pulling on something you should very quickly determine how the material will react to forces being applied in tension. The material has being pulled & you will find its strength along with how much it would be elongate. This is the method for determining behavior of materials under axial stretch loading. Data from test have used to determine elastic limit, elongation, modulus of elasticity, proportional limit, reduction in area, tensile strength, yield strength and other tensile properties.

Strain: You would also be able to found out the amount of elongation the specimen undergoes during tensile testing. This may be expressed as absolute measurement of the change in length or as relative measurement called "strain". Strain itself can be expressed in two different ways engineering strain and true strain. Engineering strain has probably the easiest and the most common expression of strain used. It is the ratio of the change in length to the original length,

$$e = (L - L_0)/L_0 = \frac{\delta L}{L_0}$$

Whereas the true strain is similar but based on the instantaneous length of the specimen as the test progresses,

$$\varepsilon = \ln\left(\frac{L_i}{L_0}\right)$$

Where L_i is the instantaneous length and L_0 is the initial length.

Specimen Shape: The specimen's shape has usually defined by the standard specification being utilized, e.g., ASTM E8 its form is main, because you would like to avoid having a break, fracture inside the area being absorbed. So norms have been developed the state to shape of the specimen to sure the break would be happen in the gage length by reducing the cross sectional area or dia. of the specimen throughout the gage length. It is the produce of increasing stress in the gage length because stress has inversely proportional to the cross sectional area under the load.

$$\sigma = \frac{Load}{Area} = \frac{P}{A}$$

Grip with Face Selection: Face and grip choice has a very important factor. By not choose the right set up. Our specimen can be slide or even fracture inside the gripped area (jaw break). This will be lead to invalid results. The faces shall cover the entire area to be gripped. You do not like to use serrated facade when testing material that are extremely ductile. From time to time cover the serrated face with masking tape will become softer the bite prevent damage in the specimen.

Specimen Alignment: Vertical aligns of the specimen is significant thing to avoid side loading or bending moment created in the specimen. Mounting the specimen in the higher grip assemblage primary then allow it to hang generously will assist to keep alliance for the test.

Figure 3.2 Specimen alignments with extension rod

In INSTRON machine tension testers or pull testers have used to find out the tensile strength of various materials from metals to plastics. These tensile testing systems utilize various technologies to apply the range of tensile forces. Standard tensile forces may be applied with electromechanical tensile tester while higher tension loads require a static hydraulic tensile system.

Furnace: These three zone resistance wire wound furnaces are of split construction to facilitate fast and easy loading the pre-assembled specimen. The case has constructed from Stainless steel with Al and hard insulation board end plates. The optional front cutout allows the use of side-entry high-temperature extensometer. Adjustable stainless steel latches keep the furnace halves locked together during use, but have then easily opened once testing has complete. The furnace has available with optional heavy duty bracket or mountings. Which attach to the wide range of testing systems. An extensive range of standard controllers has available to suit most test regimes.

Principle of operation: The resistance wire has wound on the recrystallized alumina tube in three independent zones form the furnace element. This three-zone format allows the user to tailor the furnace temperature gradient. Creating a uniform central zone, High performance ceramic fiber insulation is used (fire bricks are used) to reduce heat losses and provide fast heating rates. The specimen has heated through the combination of convection and radiation dependent in the test temperature. The furnace bore has been optimized to suit a full range of pullrods and pushrods have available to allow compatible grips to be used within our range of furnaces.

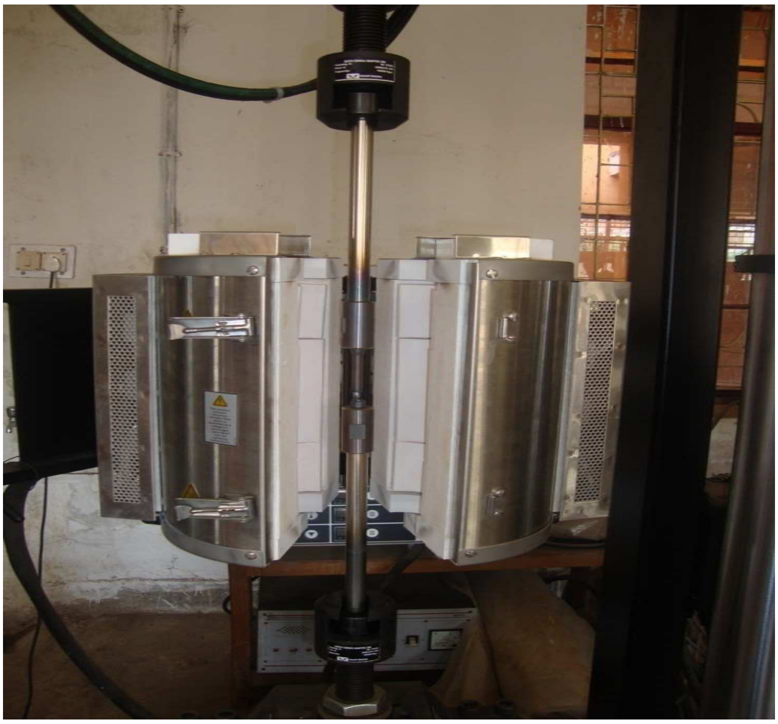


Figure 3.3 Furnace (open position)

When we increase the temperature the temperature furnace remains closed and inside the furnace three heaters will increase the temperature.

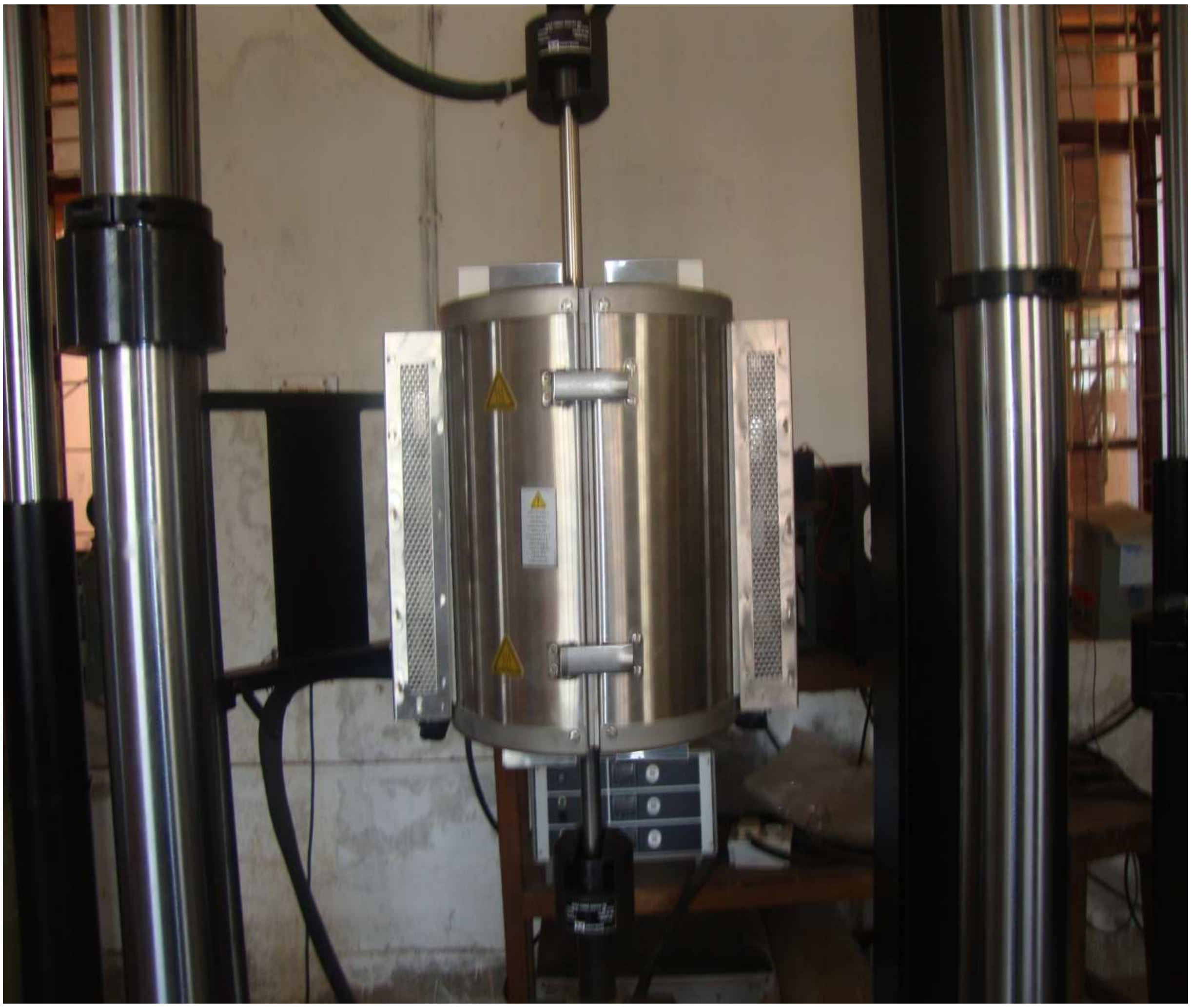


Figure 3.4 Furnace (Closed position)

Grips in furnace: A range of high-temperature specimen grips and holders is available to suit the pullrods and pushrods required. A variety of grip and holder types has available including the commonly used screw ended style.

Mounting brackets for furnace: Furnaces need to firmly attach the test system during use but also readily moved to allow access to the specimen and load string for setting-up. A variety of mounting has used depending on the furnace type and design. Roller mount has frequently used for slot-fronted furnaces. Clam-shell designs often use rotating mounts.

Figure 3.5 Hinged Furnace Mounting Bracket

Temperature Control: Temperature control systems have designed for controlling the heat output of furnaces. Chambers and ovens are controlling the cooling of chambers when connected to the liquid nitrogen source. The control systems have offered for use with new creep. Stress rupture or hot tensile systems, they can be added an existing frame using an existing furnace or chamber .The control system may either be built into the panel that has part of the frame itself or provided in the standalone cabinet to house & controls electronics and cabling connections. The systems can be configured for use with either a manual. The control systems are compatible with all furnace systems offered as the new equipment. It can be configured to operate nearly any furnace chamber or oven with any one of several different thermocouple types. Three-zone control systems have designed for heat only furnaces with three separate zones of the heating elements and typically three different thermocouples to control those zones. Single-zone control systems are designed for heat only furnaces with one zone of heating and one thermocouple. They may also be set up to control both the heating and cooling function for chambers that have both heating elements and the piped.

Figure 3.6 Temperature controller

Pull rod and push rod for furnace: A full range of pull rods and pushrods has available to allow compatible grips to be used within our range of furnaces. Pull rods and pushrods have manufactured from high temperature materials for strength and resistance to corrosion and oxidation. Specimen adaptors and holders of various designs, water-cooled adaptors and other complementary accessories have available.

Figure 3.7 Pull rod and pushrod

Threaded-End and Button-End Grip Bodies:

The bottom end holders are engineered to the further production floor testing. The hole sleeve design eradicate the require for specimen to the thread in to the holder. This is decreasing the loading time for each specimen. The open face aspect is increase the no difficulty in loading each specimen. The operator can view of specimen location throughout the loading process in INSTRON machine. The contoured rim of each hole sleeve fits firmly in the region of the switch head of shoulder end specimen. The exterior neck slides over the hole sleeves and tresses in position. That is ensuring quick, simple. Secure and reliable specimen assignment for each test. This design almost eliminates slippage of the specimen during the test when compared to lock grips. Because the key head of the specimen is enclosed with the holder. The solely mechanical process and solid steel building of all parts make sure toughness and need negligible maintenance in addition the rip sleeves are tough, increase roughness the thread end holder accumulate in a straight line onto the threaded piece of spherically seat tension rods. The threaded end specimen has then fixed into every threaded end holder. One time the specimen is located properly in the two threaded end holder. The worker may start the test.

Principle and operation:

The shoulder end holder mount openly onto the threaded piece of spherically seated tension rod projected to decrease loading time, the shoulder end holder is face open rip sleeve drawing. After placing the specimen keen on the open rip sleeve, the machinist then places the next rip sleeve above the specimen with brings the external sleeve over the assemblage. The machinist brings the outer sleeve above the specimen and bend it, the mechanism lock the specimen into place. The pre experiment load force has applied to eliminate loose amid of the grip and specimen. The spherically place tension rod would be mechanically make straight the specimen if it has located off center. This characteristic make sure the tension from the casing is applied the entire of the specimen during the period of the experiment. Shoulder end holders have designed to fulfill with ASTM E. and additional global standard and can be made to customer condition. A large range of achievable button head, shank hole and radius dimension sure compatibility. The threaded end holder build up directly onto the threaded section of the spherically place tension rod. After that the threaded end specimen is fixed into every threaded end holder. Once the specimen has situated properly in the two threaded end holders

Application rang:

- Type of Loading: Static tension
- Specimen Material wide variety of metals: Counting aluminum cast iron and steel

.Specimen type machined shoulder end specimen machined thread end specimen.

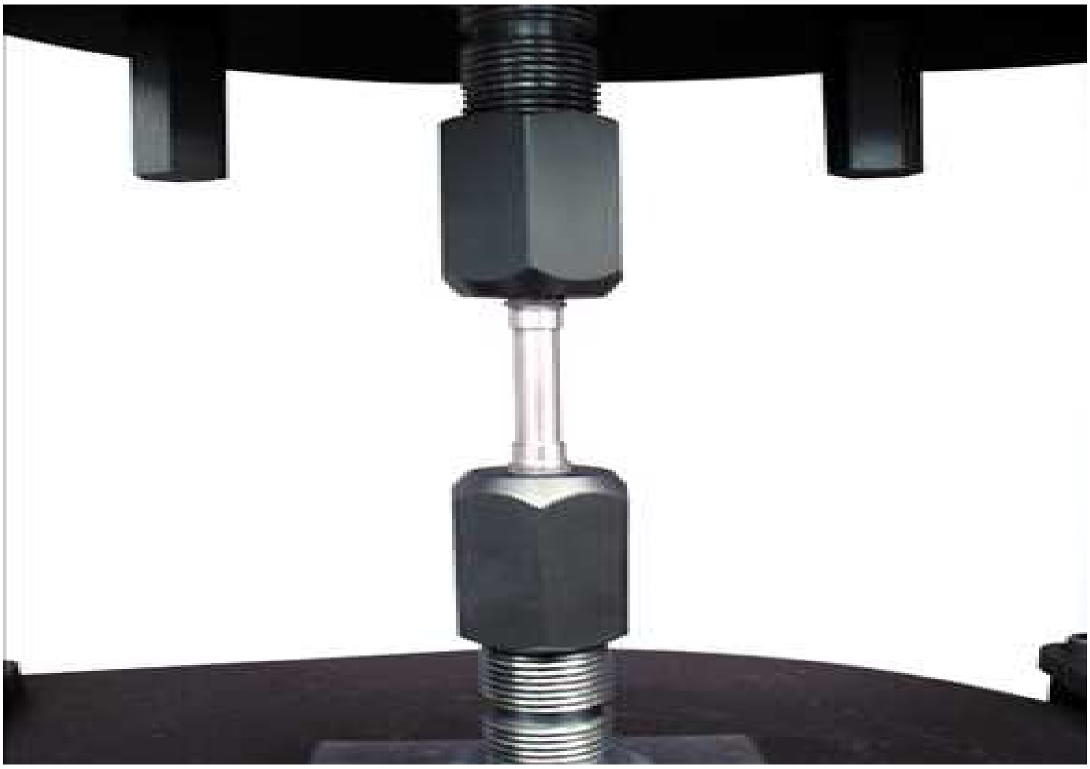


Figure 3.8 Threaded-End Specimen Holders

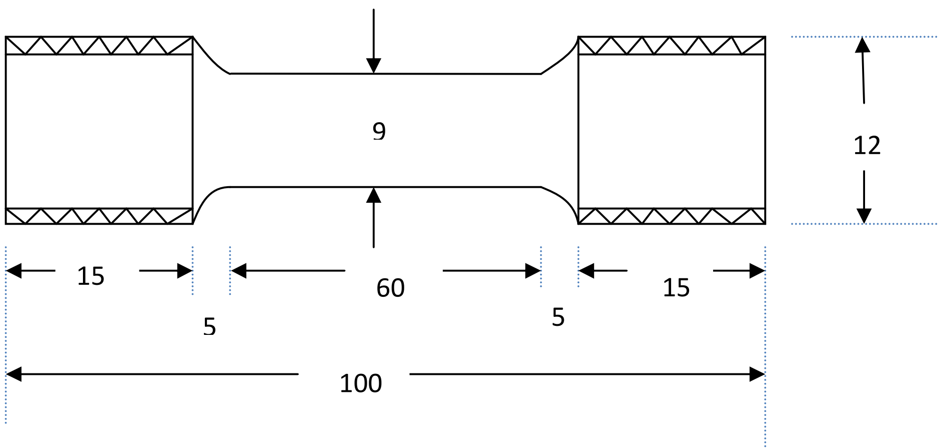
3.2 Preparation of Specimen:

Copper rod of different grades of 12 mm diameter has been taken for the preparation of specimen. Out of these two one was pure copper and second was alloy copper containing 22% carbon & 78% copper. Then these rods were cut into 10 mm segments. Now these segments were threaded at the both ends with the help of thread making Die. The figure of that die is shown below.

Figure 3.9 Thread making die of 12 mm.

After making thread the specimens were put on the lathe for turning. Where the diameter of all these specimens were reduced to 9 mm. Then fine sand paper was rubbed on the outer surface of every specimen to achieve good surface finish, and to reduce surface cracks. After that specimens got prepared for testing. The figure below shows the various dimensions of the specimen. Here all the dimensions are in `mm`.

The figure below shows the schematic diagram of the test specimen: (Where all the dimensions are in `mm`)



3.3 Tensile testing of specimens:

Now tests were conducted at different temperature ranging from room temperature to 500°C. Then whatever observations & readings have been made they were represented in the various graph.

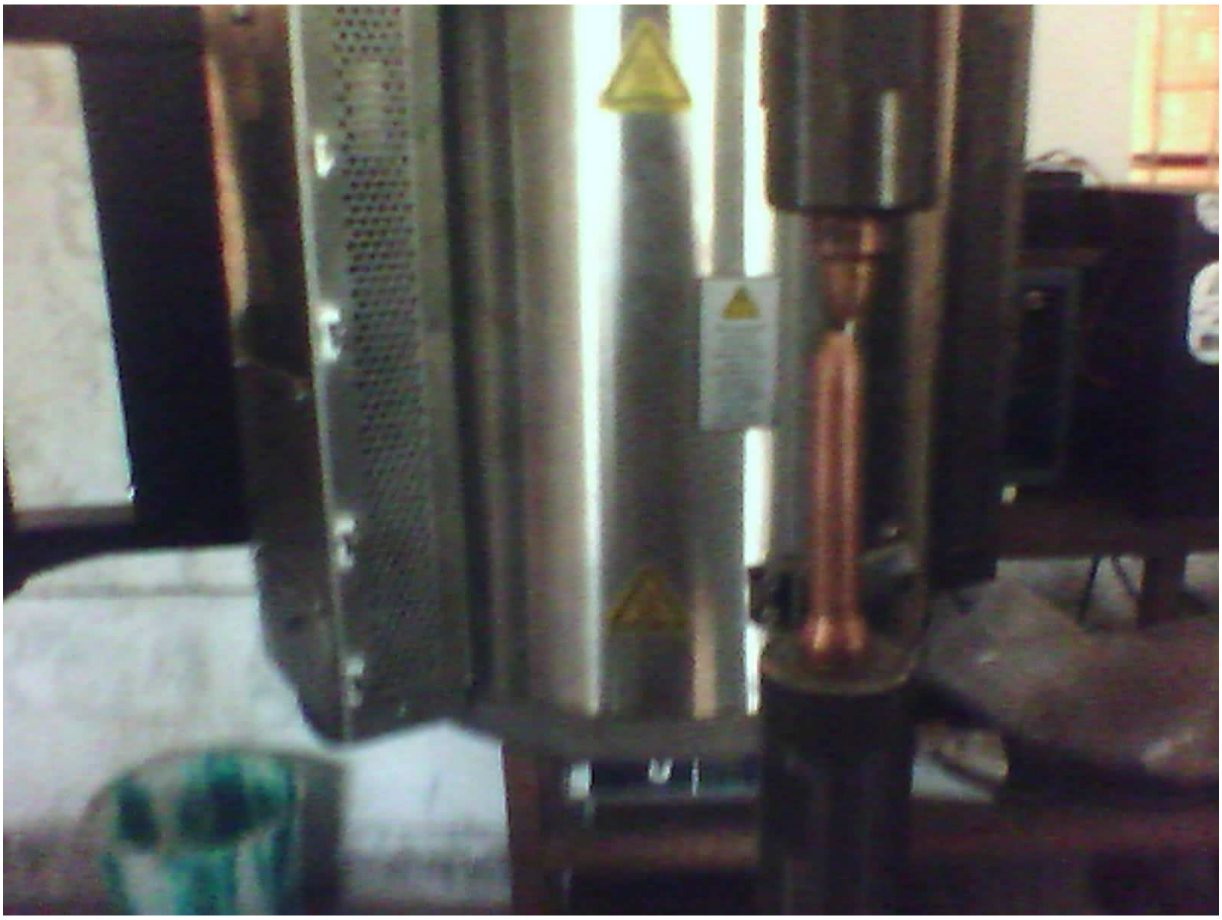


Fig. 3.10: A test specimen with furnace after fracture.

All the broken specimens after the test are shown below:

Fig. 3.11 Specimen of pure copper tested at 313K

Fig. 3.12 Specimen of pure copper tested at 323K

Fig. 3.13 Specimen of pure copper tested at 373K

Fig. 3.14 Specimen of pure copper tested at 473K

Fig. 3.15 Specimen of pure copper tested at 573K

Fig. 3.16 Specimen of pure copper tested at 673K

Fig. 3.17 Specimen of alloy copper tested at 313K

Fig. 3.18 Specimen of alloy copper tested at 323K

Fig. 3.19 Specimen of alloy copper tested at 373K

Fig. 3.20 Specimen of alloy copper tested at 473K

Fig. 3.21 Specimen of alloy copper tested at 673K

Chapter-4

Results & Discussion.

Results and Discussions:

Tests were conducted on pure & alloy copper at different temperature ranging from room temperature to 500°C. The values of % Elongation for pure & alloy copper at different temperatures are given in table no. 4.1. Similarly the variations of Ultimate Tensile Stress & 0.2 % Yield Stress with Temperature and variation of Strain hardening Exponent `n` & Strengthening coefficient `A` with Temperature are given in Table no. 4.2, 4.3, 4.4 respectively.

4.1 Variation of % Elongation with temperature:

Table 4.1: % Elongation-Temperature (for pure & alloy copper)

Temperature		% Elongation	% Elongation
°C	K	Pure Copper	Alloy Copper
RT (40)	313	11.74	11.32
50	323	11.01	10.74
100	373	10.38	10.14
200	473	10.19	10.00
300	573	5.56	
400	673	3.70	2.83
500	773	0.8699	

Fig. 4.1 shows the above values in graph. The % Elongation decreasing with increase in temperature both for pure and alloy copper but after 323K variation in % Elongation is more for alloy copper than for pure copper.

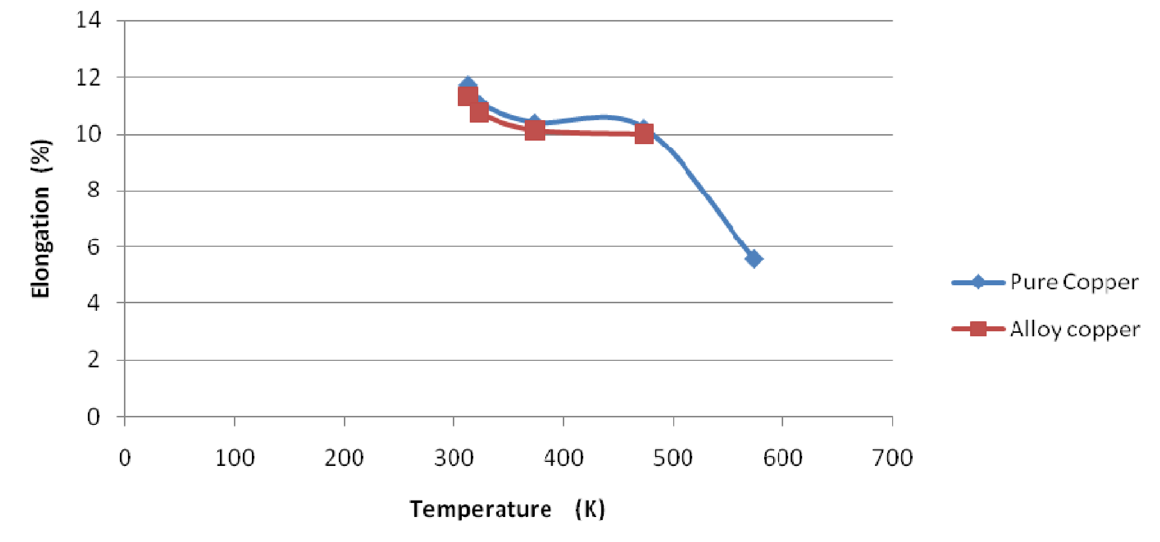


Fig. 4.1 : % Elongation-Temperature

4.2 Variation of Tensile stress with Tensile Strain:

From the Fig. 4.2 it is clear that initially there is a linear relationship between tensile stress and tensile strain up to certain limit, at every temperature, both for pure and alloy copper; and after that there is a large increase in tensile strain with slightly increase in stress. Then after yield point tensile strain increases drastically with decrease in stress.

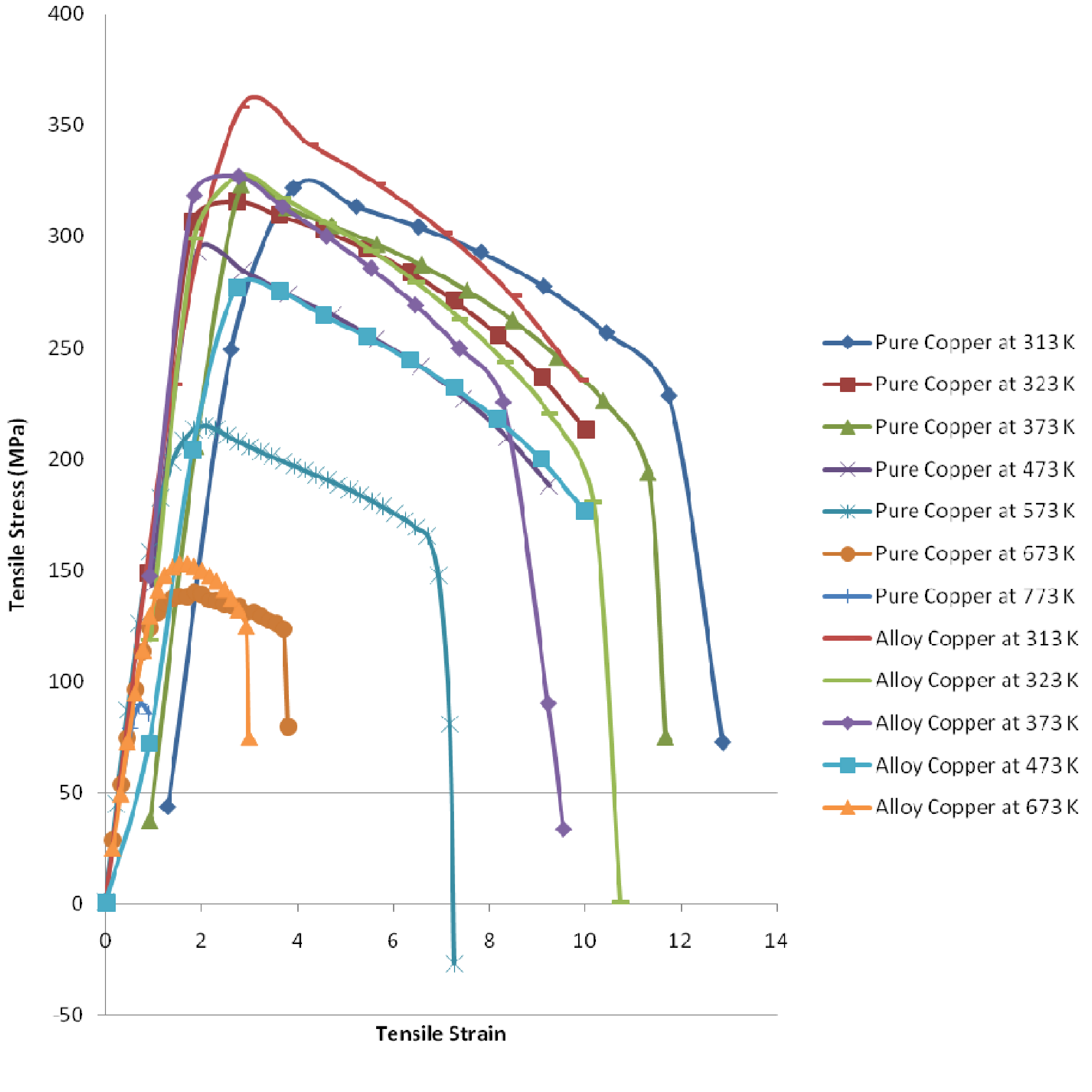


Fig. 4.2 : Tensile stress-tensile strain

4.3 Variation of Ultimate Tensile Strength with Temperature (K):

The table below contains various values of Ultimate tensile strength at different temperature both for pure and alloy copper.

Table 4.2: Values of ultimate tensile strength at different temperature

Temperature		Ultimate Tensile Strength (MPa)	
^{o}C	K	Pure Copper	Alloy Copper
RT (40)	313	321.9303	358.288
50	323	315.6867	327.5451
100	373	305.0205	327.2151
200	473	293.0951	276.8412
300	573	213.3571	
400	673	140.2233	129.4644
500	773	89.548	

From the fig. 4.3, it can be seen that there is a slightly decrease in ultimate tensile strength up to 473K and after that there is a large decrease in ultimate tensile strength with temperature, both for pure and alloy copper.

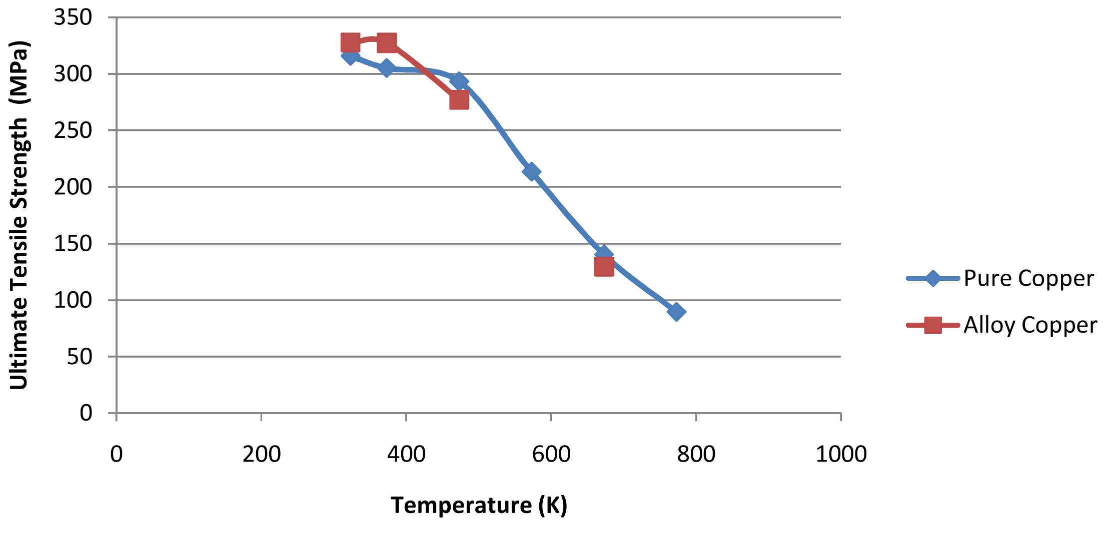


Fig. 4.3 : Ultimate tensile Strength-Temperature

4.4 Variation of 0.2 % offset Yield strength with Temperature (K):

From the values of the tensile stress and tensile strain for different specimens the tensile stress-strain curve has been plotted and then with the help of 0.2% offset method the values of yield strength was found out for each specimen tested at different temperature. These values are tabulated in table no 4.3.

Table 4.3: Values of 0.2 % yield stress at different temperature

Temperature		0.2% offset yield stress(MPa)	
^{o}C	K	Pure Copper	Alloy Copper
RT (40)	313	300	355
50	323	310	327.55
100	373	312	327.20
200	473	270	280
300	573	205	
400	673	130	140
500	773	85	

From fig.4.4, it is clear that the values of 0.2% yield strength of pure copper is increasing with temperature up to 373K and after that it is decreasing drastically; but for alloy copper there is a slightly decrease in 0.2% Yield strength up to 373K and after that there is a large decrease is found.

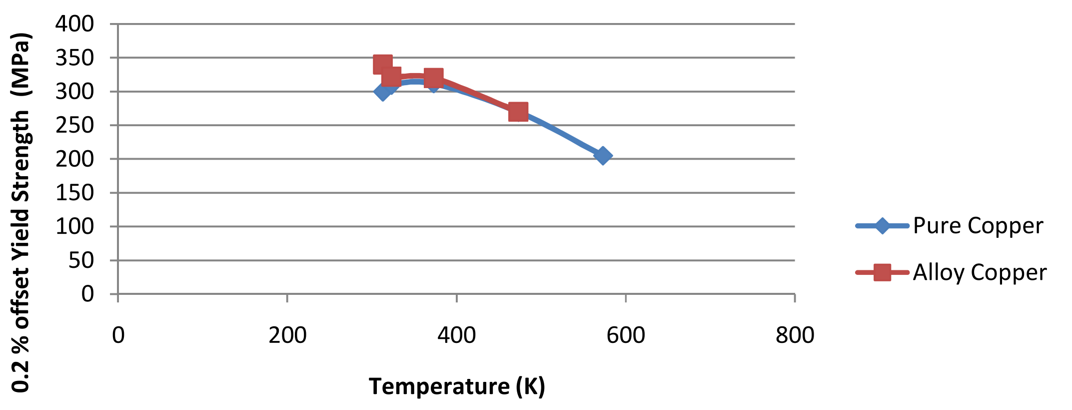


Fig. 4.4: 0.2% offset Yield strength- Temperature

4.5 Variation of True Stress with Time:

Fig.4.5. shows the variation of True Stress with Time. There is a linear relationship is found between True stress and Time up to certain limit and after that there is a negligible increase in True stress with large increase in time. But for alloy copper at 473K the line (which shows the variation of True Stress with Time) is very near to the vertical axis. Which means that the values of True Stress for alloy copper at 473K is increasing very fast within very less time.

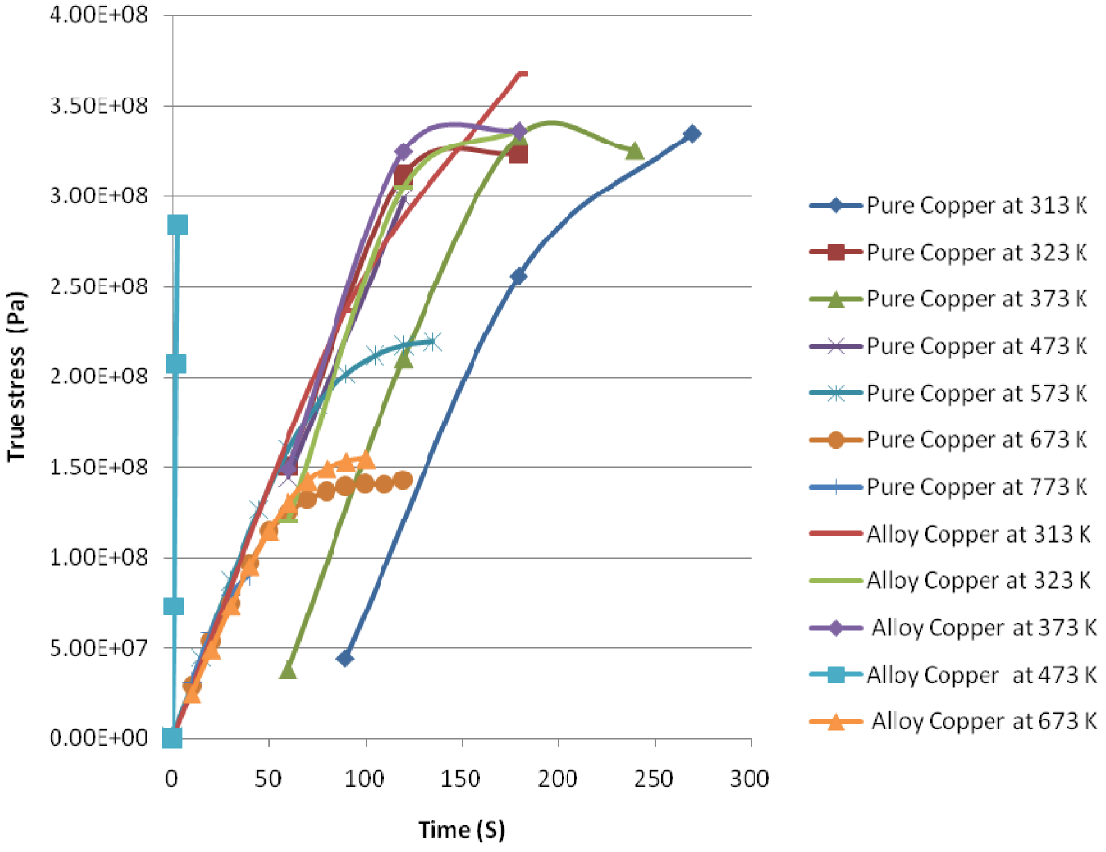


Fig. 4.5: True stress-Time

4.6 Variation of True Stress with True Strain:

The variation is shown in the Fig.4.6. Which shows a linear relationship between True Stress and True Strain (both for pure and alloy copper) up to certain limit, and after that for same values of True Stress there is a large increase in True Strain. Then there is a decrease in True Stress with further increase in True Strain, is found.

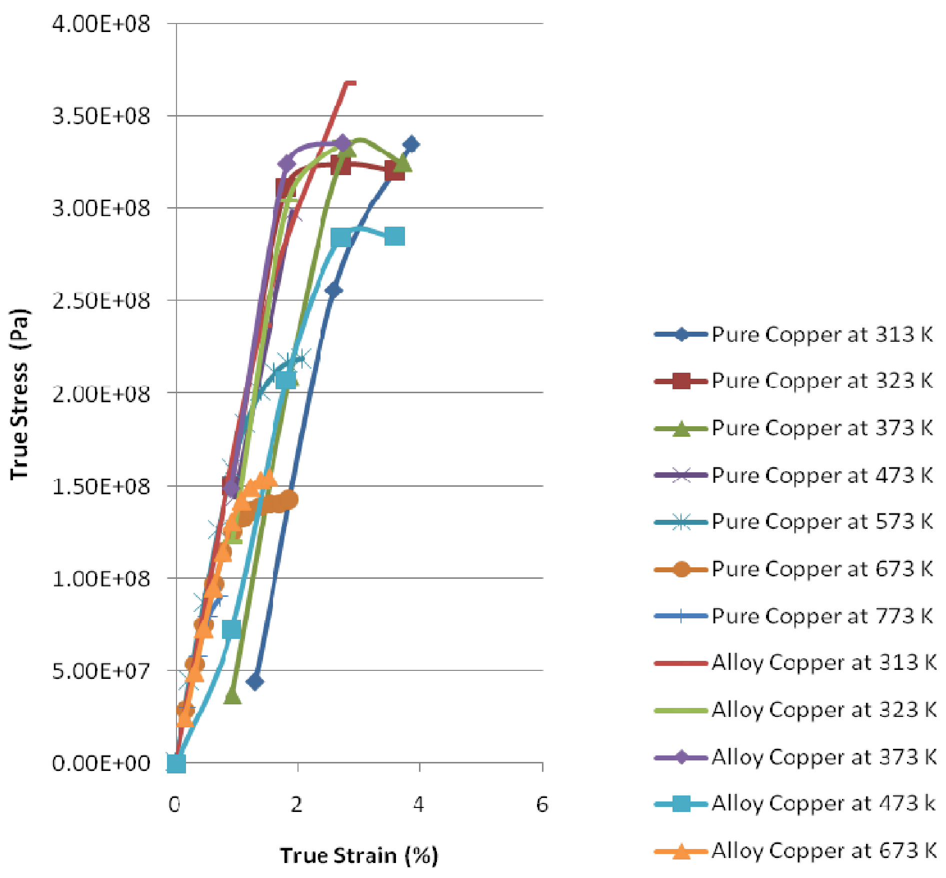


Fig.4.6 : True stress-True Strain

4.7 Variation of strain hardening exponent `n` With Temperature `K`

The values of `A` strengthening coefficient, & `n` the Strain Hardening Exponent at different Temperature were found out from the True Stress & True Strain value of each specimen. Which are as follows:

Table 4.4: Values of Strain hardening Exponent `n` and Strengthening coefficient `A`

Temperature		Pure Copper		Alloy Copper	
^{o}C	K	A	n	A	n
RT (40)	313	156	.99	185	.69
50	323	154	.91	232	.39
100	373	138	.78	296	.14
200	473	135	.73	270	.07
300	573	129	.41		
400	673	124	.298	146	.06

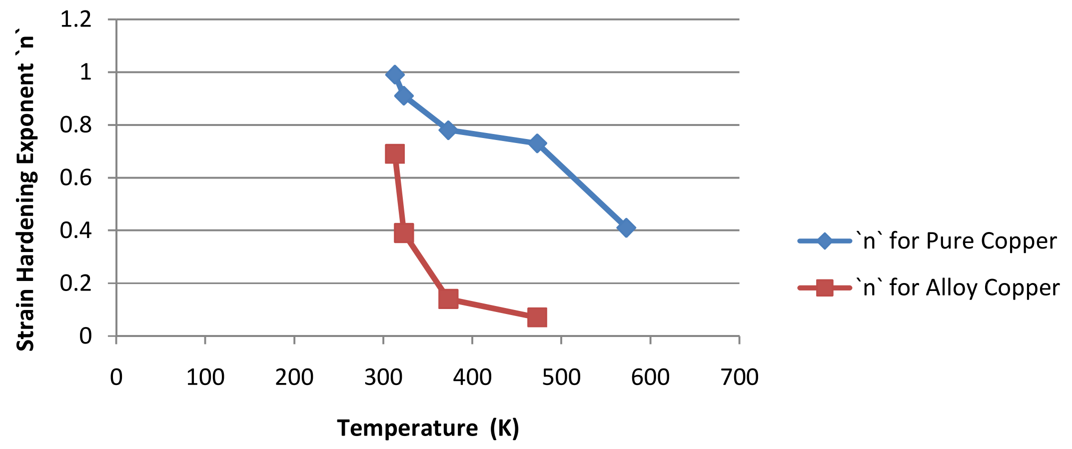


Fig.4.7 Strain Hardening Exponent-Temperature

The variation of Strain hardening Exponent `n` with Temperature is shown in fig.4.7. From Fig. it is clear that with increase in Temperature the Strain hardening Exponent `n` decreases both for Pure & Alloy copper. But the decreasing rate is higher for Alloy copper than for Pure Copper.

Fitting the Characteristic equations: From the above curves the Characteristic equations for the material $[\sigma = A\varepsilon^{n}]$ have been derived at different temperature; which satisfy all the points present in the curve. These equations are the power law equations.

A. For Pure Copper:

1. Power law equation at temperature 313 K

$$\sigma = (156)\varepsilon^{.99} \text{ MPa}$$

2. Power law equation at temperature 323 K

$$\sigma = (154)\varepsilon^{.91} \text{ MPa}$$

3. Power law equation at temperature 373 K

$$\sigma = (138)\varepsilon^{.78} \text{ MPa}$$

4. Power law equation at temperature 473 K

$$\sigma = (135)\varepsilon^{.73} \text{ MPa}$$

5. Power law equation at temperature 573 K

$$\sigma = (129)\varepsilon^{.41} \text{ MPa}$$

6. Power law equation at temperature 673 K

$$\sigma = (124)\varepsilon^{.298} \text{ MPa}$$

A. For Alloy Copper:

1. Power law equation at temperature 313K

$$\sigma = (185)\varepsilon^{.69} \text{ MPa}$$

2. Power law equation at temperature 323K

$$\sigma = (232)\varepsilon^{.39} \text{ MPa}$$

3. Power law equation at temperature 373K

$$\sigma = (296)\varepsilon^{.14} \text{ MPa}$$

4. Power law equation at temperature 473K

$$\sigma = (270)\varepsilon^{.07} \text{ MPa}$$

5. Power law equation at temperature 673K

$$\sigma = (146)\varepsilon^{.06} \text{ MPa}$$

Table 4.4 shows the values of strengthening coefficient `A` and Strain Hardening Exponent `n` at different temperature. From the table and the characteristic equation at different temperature it is clear that there is a decrease in `n` with increase in temperature both for Pure Copper & Alloy Copper. Similarly the values of `A` for Pure

Copper decreases with increase in Temperature but for Alloy Copper it increases initially up to temperature of 373K and after that decrease, due to phase change of carbon atoms (present in the Alloy Copper) at higher Temperature.

The above equations are the characteristic equations of the material at a particular Temperature. To find out a General Characteristic Equation of the material, simple least square method has been used and the following equations have been proposed. These are the Temperature dependent equations.

For Pure Copper:

$$\sigma = 156 \times (3.593\ K^{-0.22})\varepsilon^{0.99(1.569-0.001K)} \text{ MPa}$$

For Alloy Copper:

$$\sigma = 185 \times (-2 \times 10^{-5}\ K^{2} + 0.01K - 2.343)\varepsilon^{0.69(1\times10^{7}K^{-2.97})} \text{ MPa}$$

Where, σ = Stress

ε = Strain

K = Temperature in kelvin.

Chapter-5

Conclusions

Conclusions:

Based on the results obtained, the following conclusions have been drawn on the high temperature behavior of pure & alloy copper.

- Substantial decrease in yield and ultimate strength of both pure & alloy copper were observed with increasing test temperature. But the value of these strength were slightly higher for alloy copper than that of pure copper for every test temperature.
- The ductility i.e. % elongation as well as the strain hardening exponent \`n\` for pure copper was slightly higher than that of the alloy copper at every test temperature.
- Ductile fracture with equiaxed dimples were mode of fracture found even at elevated temperature in pure as well as alloy copper.
- Substantial decrease in Strain Hardening Exponent \`n\` with increase in Temperature both for pure & alloy copper were observed; but the strengthening coefficient \`A\` decreases with increase in temperature for Pure Copper, and initially increases up to 373K and after that decreases for Alloy Copper, due to phase change of carbon atoms (present in Alloy Copper) at higher Temperature. A generalized characteristic equation for both tested materials has been proposed, which can take effect of temperature.

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